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DISCUSSION OF DEFLECTION OF PLYWOOD BEAMS DUE TO MOISTURE CONTENT CHANGE

(*Published in April, 1949*)

By M. W. Jackson, and W. E. Wilson and Laurence G. Olson

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DISCUSSION

M. W. Jackson,[3] Jun. ASCE.—An excellent job has been done by the authors in studying the effect of moisture change on the deflection of plywood beams. The experimental data presented in Fig. 8 may be used in calculations for the dimensional change in plywood due to moisture.

Since specific data about the plywood used were not given, it will be assumed to be the commonly used five-ply Douglas fir. For Douglas fir wood, longitudinal shrinkage is about 0.1%, and values for radial and tangential shrinkage are 5.0 and 7.8, respectively, from green (36% moisture) to oven dry condition.[4] The average shrinkage of cross plies in which the grain is variable could be assumed as about 6.4%. The wood does not begin to shrink from the green condition but remains unchanged in dimension until the fiber saturation point has been reached in drying—at about 25% moisture.[5] Consequently, for a 1% change in moisture, the shrinkage across the plies would be 6.4/25 = 0.255%, or about 0.0025 in. per in. per 1% moisture change.

Internal stresses are set up in the plywood by moisture changes because of the tendency of the cross plies to shrink, while the length of the parallel plies tends to remain practically unchanged. Unrestrained, the cross plies would shrink about $2\frac{1}{2}$ in. in an 8-ft panel for a moisture decrease of 10%. An examination of these internal stresses across any given section in a panel indicates that the induced load on the cross plies, P_c, must be equal to the load on the parallel plies, P_p; that is, $P_c = P_p$. Consequently,

$$P_c = A_c\, s_c \qquad (16a)$$

and

$$P_p = A_p\, s_p \qquad (16b)$$

in which A and s are the areas and stresses in the respective plies. Since $A_c = 0.240$ sq in. and $A_p = 0.360$ sq in. per in. of width in a normal panel, then $s_p = \frac{2}{3}\, s_c$. Expressing the stress on the section in terms of the unit deformation, ϵ, and the modulus of elasticity, E,

$$s_c = E_c\, \epsilon_c \qquad (17a)$$

$$s_p = E_p\, \epsilon_c \qquad (17b)$$

Note.—This paper by W. E. Wilson and Laurence G. Olson was published in April, 1949, *Proceedings*. The numbering of footnotes, equations, and illustrations in this preprint is a continuation of the consecutive numbering used in the original paper.

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[4] "Strength and Related Properties of Woods Grown in the United States," by L. J. Markwardt and T. R. C. Wilson, *Technical Bulletin No. 479*, U.S.D.A., Washington, D. C., 1935.

[5] "A Primer of Chemical Seasoning," by D. F. Hill and A. L. Mottet, West Coast Lumbermen's Assn., Seattle, Wash., 1945.

and

$$E_p \epsilon_p = \frac{2}{3} E_c \epsilon_c \ldots\ldots\ldots\ldots\ldots\ldots (17c)$$

The modulus of elasticity for parallel plies is 1,600,000 lb per sq in.; but, across the grain, it is only 80,000 lb per sq in. or less, depending on the direction of grain. If ϵ is the unit deformation of the parallel plies produced by shrinkage of the cross plies, the unit deformation of the cross plies is $0.00255 - \epsilon$. Evaluating, $1{,}600{,}000\ \epsilon = \frac{2}{3}\ (0.00255 - \epsilon)\ 80{,}000$, and $\epsilon = 0.000082$ in. per in. per 1% moisture change. The total deformation for an 8-ft panel for 10% moisture change is 0.079 in. This result almost doubles the values from the experiments given in Fig. 8. It should be noted that, although the value for E across the grain is usually given as 80,000 lb per sq in., it may vary from 12,000 lb per sq in. to 76,000 lb per sq in., depending on the direction of grain across the cross section.[6] If an average value of 44,000 lb per sq in. is used for E, then the total deformation becomes 0.044 in., in accordance with the actual test data shown in Fig. 8.

This theory does not explain the erratic results for the lower moisture contents. Possibly they may be caused by the facts that the effect of moisture content on the modulus of elasticity is little understood and that there is no experimental assurance that E is constant for all moisture contents. At the lower moisture contents possibly the moisture was not distributed uniformly through the specimen, and also possibly variations in humidity may have introduced discrepancies.

The internal stresses in the plywood on the basis of the foregoing analysis are of interest. In the parallel plies, for a change of moisture content of 10%, $s_p = E_p\ \epsilon_p\ 10 = 1{,}600{,}000 \times 0.000046 \times 10 = 740$ lb per sq in.; and, for the cross plies, $s_c = 1{,}110$ lb per sq in. These internal stresses are of considerable magnitude. The stress in the cross plies is apparently roughly equal to the ultimate strength for standard tests of small clear specimens in tension and compression across the grain, but the effect of size in transferring stresses from such standard tests to the condition in the plies is unknown. Since the modulus of elasticity in direct tension and the modulus of elasticity in direct compression for wood are not equal and since some permanent deformation probably results from each cycle of moisture change, plywood will eventually deteriorate under repeated changes in moisture content.

It would be interesting to know the effect of permanent loads on specimens like those tested, since the effective modulus of elasticity decreases with time. In Fig. 11(*b*) it is difficult to discover which set of points is based on the full thickness and which set is based on the effective thickness mentioned under the heading, "Analysis of Data."

The symbol t_2, for thickness of the lower flange introduced in Eq. 12, does not appear in Eq. 15. Since the investigation was prompted by the warping of box girders with unequal flanges, it would be of interest to compare the effects when using unequal and equal flanges.

[6] "Wood Handbook," Forest Products Laboratory, U. S. D. A., Washington, D. C., 1940.

W. E. WILSON,[7] ASSOC. M. ASCE, AND LAURENCE G. OLSON.[8]—Mr. Jackson presents an interesting discussion of the internal stresses in a piece of plywood subject to varying moisture content. He also raises a very pertinent question concerning the interpretation of Fig. 11(*b*). In Fig. 12 the data in Fig. 11(*b*) are analyzed by plotting the measured slope of the curve of Fig. 11(*b*) against

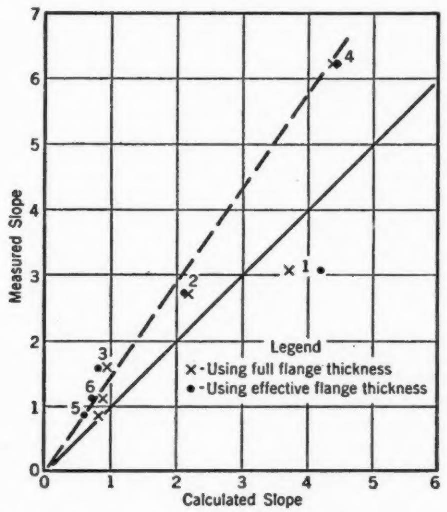

FIG. 12.—COMPARISON OF MEASURED AND COMPUTED SLOPES $\frac{\Delta D}{\Delta m}$, OF THE MAXIMUM DEFLECTION CURVE

the calculated slope of the theoretical curve (also shown in Fig. 11(*b*)) for beams 1, 2, and 4. The broken line in Fig. 12 fits the experimental points fairly well. If theory and experiment agreed precisely, the solid line in Fig. 12 would pass through the experimentally determined points.

The value of M given (under the heading, "Analysis of Data") is the slope $\frac{\Delta m}{\Delta L}$ of the solid line in Fig. 8, multiplied by the length of the specimen.

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